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PROPAGATION OF EXPLOSIVE SOUND IN THE BIFI RANGE.(U)
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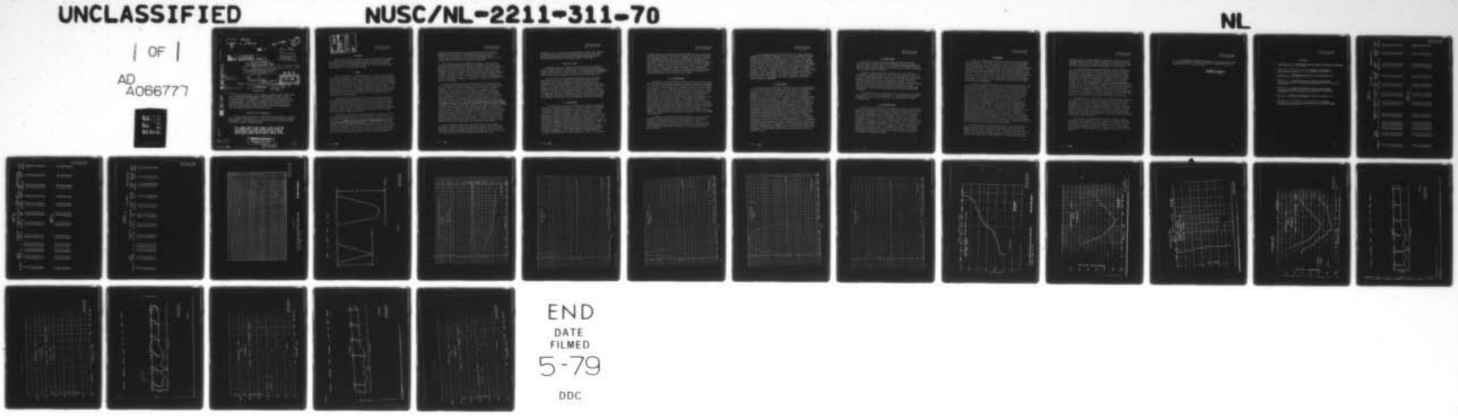

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NEW LONDON LABORATORY
NAVAL UNDERWATER SYSTEMS CENTER
NEW LONDON, CONNECTICUT 06320

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PROPAGATION OF EXPLOSIVE SOUND IN THE BIFI RANGE,

by

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(16) F11552

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INTRODUCTION

This memorandum deals with a series of acoustic tests conducted in Block Island Sound. ~~between August 1967 and October 1968.~~ In these tests~~, referred to as "Experiment 2" in Reference 1,~~ propagation loss is measured under a wide range of thermal conditions, using explosives as sound sources. The values of propagation loss obtained are compared with those values predicted by normal mode theory. The first two tests of the series, conducted in August 1967 and January 1968, were discussed previously in References 2 and 3.

ADMINISTRATIVE INFORMATION

This memorandum was prepared under NUSC/NL Project Title: Shallow Water Acoustic Investigation, W. R. Schumacher and B. Sussman, Principal Investigators. The sponsoring activity was Naval Ship Systems Command, Code OOVI, J. Reeves, Program Manager.

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PROCEDURE

For all the tests discussed, explosives were detonated at depths of 50 and 75 feet at point A. Figure 1, near Block Island. Signals were received by a bottom-mounted hydrophone located at a depth of 155 feet at point B, off Fishers Island. The explosive charges used were either 1/2 or 1 pound blocks of TNT.

THEORY

Most of the theory of sound propagation by normal modes has been discussed in References 4 and 5. Reference 4 contains a description of NUSC/NLLAB Program S1441 which deals with normal mode propagation over a flat homogeneous bottom in a medium whose velocity profile is constant with distance from an acoustic source. Reference 5 describes NUSC/NLLAB Program S1548 which uses normal mode theory to predict acoustic propagation over an ocean bottom whose depth and acoustic impedance vary slowly with range and in a medium whose velocity profile varies slowly with distance from an acoustic source. These two procedures will be referred to as normal mode predictions for a flat bottom and an irregular bottom, respectively.

The prediction of propagation loss for a flat bottom is determined by the depth, velocity profile, and bottom characteristics, all of which are assumed constant with distance from an acoustic source. The prediction of propagation loss for an irregular bottom is dependent on the values of these three parameters at both the source and receiver. Thus, when the parameters have large variation with distance from an acoustic source, the two methods can predict significantly different values of propagation loss.

One special case should be mentioned where the predicted values do indeed vary significantly. It occurs when velocity profile and bottom characteristics remain relatively constant over an entire range but there is a large variation between the depth assumed for a flat bottom at either the source or receiver.? Vertexing of the rays can account for a marked disparity between the sound fields at the receiver. As shown in Figure 2, h_1 is the assumed depth for a flat bottom case and h_2 is the depth at the source or receiver in the irregular bottom case; the source or receiver is at the bottom. In the irregular but not the flat bottom case the element is in a "shadow zone" and the

calculated propagation loss is consequently much larger since the amplitude of the pressure field shows an exponential decay in a "shadow zone" (Reference 3). The example considered occurs in the winter where h_1=110 feet is the average depth used for a flat bottom and h_2=150 feet is the depth at the receiver.

It has been previously determined (References 2 and 3) that at the frequencies considered in these tests (about 56 to 560 Hz), the first mode predominates in the signals received at Point B in Figure 1. Therefore, it has been assumed in the theoretical calculations of propagation loss that the pressure field at the receiving hydrophone contains only the first mode. Since the first mode is dominant, there is little difference in the pressure field, produced by explosives, detected at 50 and 75 feet. As in References 2 and 3, the measurements at the two depths are combined. Theoretical calculations are for a source 75 feet deep.

Let us consider the general characteristics of propagation loss as a function of frequency. Figure 3 is a typical plot of excitation pressure versus frequency for the first mode. Excitation pressure decreases with frequency at the frequencies considered in this memorandum. Thus, less energy goes into the higher frequency modes and, considering this factor alone, propagation loss will increase with increasing frequency. It is possible (Reference 3) to construct a ray equivalent of a particular mode as shown in Figure 4; it is therefore possible to determine the skip distance between bounces off the bottom of the medium. The angle at which energy strikes the surface or bottom, relative to the normal to the bottom, increases with frequency (Reference 3). Thus, as shown in Figures 4 and 5, the skip distance tends to increase with frequency thereby reducing the number of bounces over a given range. However, if a velocity gradient exists in the medium, the skip distance increases with the frequency until there is a vertexing at the interface as presented in Figure 6. In general, this represents the largest skip distance attainable. As the frequency is increased further, the depth of the vertexing recedes from the interface and the skip distance decreases as shown in Figure 7. Thus, propagation loss will decrease with frequency due solely to the effect of skip distance; however, the effect of vertexing can modify this relationship.

In the irregular bottom case many depths and velocity profiles may exist. Obviously, then, there are many possible ways to determine the skip distance. An average skip distance could be taken over the sections of an acoustic range. However, the sections of that range with the largest gradients should produce the greatest effect on

propagation loss. Therefore, in the analysis of these tests, whenever the velocity profile varied considerably over the range, the skip distance was determined by using the largest gradient measured at a depth which was close to the average depth of the range.

RESULTS OF TESTS

Propagation loss as a function of frequency was determined for all five tests conducted. These results were obtained by finding the energy content of each received shot for a 1 Hz-band at logit frequencies from 56 to 562 Hz. The levels thus derived were subtracted from the source level for the explosives as given by Weston (Reference 6.)

For every test the theoretical propagation loss values were calculated in both the irregular and flat bottom cases with the assumption that no bottom loss was suffered by the first mode. Velocity profiles were used which had been measured at the time of tests. In the flat bottom case, the velocity profile with the largest gradient was chosen to apply to the whole range if more than one profile was taken. The water depth assumed for the flat bottom was 110 feet. The difference between experimental and theoretical values of propagation loss was interpreted as a measure of bottom loss, and the internal consistency of the theoretical and experimental results was observed. The outcomes of the individual tests are given below.

A. AUGUST 1967

The August 1967 tests were conducted when the velocity profile possessed a large negative gradient as shown in Figure 8. Since this was the only velocity profile taken during the tests, it was used to represent velocity conditions over the entire range. As may be seen from the plot of propagation loss as a function of frequency appearing in Figure 9, the curve is nonlinear with a minimum at 141 Hz. These results and the theoretical anlysis are given in Table 1. The differences between theoretical predictions of propagation loss for the flat and irregular bottom cases are small, since in both cases only one velocity profile was used to represent the entire range. The increase in theoretical loss with frequency is due mainly to the variation of the excitation pressure with frequency (as discussed in the previous section). The change in skip distance with frequency is shown in Figures 4-7; at low frequencies, the skip distance increases with frequency, as shown in Figures 4 and 5. This increase

continues until a frequency is reached at which the ray vertexes near the surface (Figure 6). This event corresponds to 141 Hz in Table I, at which point the skip distance is a maximum and the angle at which the energy first strikes the surface becomes 90°. Thereafter, as presented in Figure 7, the ray vertexes at increasing depth for higher frequencies and the skip distance decreases. The loss per nautical mile is a minimum at 141 Hz and the loss per bounce is on the order of 0.5 dB over the frequency range considered. The maximum loss per bounce was determined to occur at 141 Hz, which is probably due to the assumption that the particular velocity profile measured is a good approximation at all points along the range.

B. JANUARY 1968

The tests in January 1968 were conducted when a typical velocity profile had a small positive gradient as given in Figure 10 (Reference 7). All five profiles taken over the range were similar to that shown in Figure 10. For the purpose of comparison, Figure 11 exhibits plots of propagation loss as a function of frequency for these and the August 1967 tests. It can be seen that propagation loss was much greater in August than in January, and that the difference in propagation loss for these two sets of tests is particularly large for frequencies above 200 Hz. The results and theoretical analysis pertaining to the January tests are shown in Table II. The predicted propagation loss values for an irregular bottom are much larger than those for a flat bottom, especially at the higher frequencies. This circumstance is attributed to the previously described effect caused by irregularity in depth near the receiver and a positive velocity gradient. In both cases the predicted propagation loss increases with frequency as expected. The skip distance increases with frequency since vertexing would not occur until the frequency was increased to about 700 Hz and θ_v would equal 90°.

It should be noted that the physical pictures suggested by the analysis of a flat and an irregular bottom differ. In the former analysis, the loss per bounce is on the order of .2 dB at all frequencies considered. However, the skip distance increases (number of bounces decreases) with frequency and thus bottom loss decreases with frequency as demonstrated by values of bottom loss in dB per nautical mile.

In the irregular bottom analysis the loss per bounce decreases sharply with increasing frequency as the angle of incidence of energy striking the bottom, θ_b increases from 74.4° to 89.3°. This, when combined with the increase in skip distance with frequency, explains the decreased bottom loss with frequency. At frequencies of 355-562 Hz the predicted values of propagation loss are lower than the measured values by about 2 dB and bottom loss and loss per bounce are negative. At low frequencies the skip distances for both August and January are about the same. However, the angle of incidence is larger during January, a fact which explains the decrease in propagation loss in January at these frequencies. At higher frequencies, both the angle of incidence and skip distance are larger in January. Thus, the larger increase in propagation loss at the higher frequencies in the two months is explained.

C. APRIL 1968

The tests in April 1968 were conducted when the velocity profile varied considerably over the range as shown in Figure 12 (Reference 7). As can be seen, the profile possessed a small negative gradient approximately 18 miles from the source and a fairly large negative gradient in the middle of the range. For comparison, a plot of propagation loss as a function of frequency for the April and January tests is shown in Figure 13. It is apparent that the propagation loss at most frequencies was slightly greater in April than in January. The April results and theoretical analysis are presented in Table III. The differences between the theoretical propagation loss predictions for a flat and an irregular bottom are small since there is little variation in the velocity profile near the source and receiver. As expected, the theoretical propagation loss increases with frequency. The results concerning skip distances and angles of incidence at the surface and bottom were calculated using the velocity profile in Figure 12 about 12 miles from the source. One can see by comparing the values of skip distances and θ_b in Tables II and III that these quantities are nearly the same in January and April for low frequencies and similar losses would be expected. However, at higher frequencies the skip distances and θ_b are greater in January and one would expect slightly lower values of propagation loss in January; this seems to be the case. The differences, though, at 112 and 141 Hz are larger than anticipated. The loss per bounce in the frequency range was on the order of 0.3 dB.

D. AUGUST 1968

The tests in August 1968 were conducted when the velocity profiles taken over the range exhibited large negative gradients as shown in Figure 14 (Reference 7). The profiles were taken on the day after the tests were performed. The profile near the source possessed only a slightly negative gradient.

Figure 15 gives a plot of propagation loss as a function of frequency for the August 1968 tests and for the August 1967 test. It can be seen that the propagation loss at most frequencies was slightly greater in 1968 than in 1967. These results and the theoretical analysis for the 1968 tests are provided in Table IV. There are moderate differences between the theoretical predictions of propagation loss for a flat and an irregular bottom, since there is only a moderate difference between the velocity profiles at the source and the receiver. The theoretical propagation loss again increases with frequency.

The skip distance is a maximum at 178 Hz, compared with a maximum skip distance at 141 Hz in August 1967. In August 1968 the minimum propagation loss at 141 Hz is slightly less pronounced than that of August 1967.

E. SEPTEMBER 1968

The September 1968 tests were performed when the velocity profiles taken over the range exhibited moderately negative gradients as shown in Figure 16 (Reference 7). The profiles, obtained two days after the tests were conducted, near the source and receiver were less negative than those toward the center of the range. Figure 17 is a plot of propagation loss as a function of frequency for the September 1968 and August 1967 tests. The loss is lower in August at low frequencies and lower in September at the higher frequencies. Table V shows that in September the maximum skip distance occurs at 355 Hz. Since the skip distance is a maximum at 141 Hz in August, it is not surprising that relatively less loss occurs at the higher frequencies in September and at the lower frequencies in August. This is due to the fact that skip distances are longer in August at lower frequencies and longer in September at higher frequencies.

CONCLUSIONS

The results derived from these tests are consistent with normal mode predictions. Three major factors account for the relationship between propagation loss and frequency. First, excitation pressure decreases with frequency, which has the effect of increasing propagation loss with frequency. Second, skip distance in general increases with frequency, decreasing propagation loss with increasing frequency. In the BIFI range these two effects seem to cause the minimum propagation loss at a frequency around 100-200 Hz. This minimum is either enhanced or depressed by the third factor, the frequency at which vertexing commences. If it occurs near the minimum as in August 1967 and 1968, the minimum is enhanced; if it is away from the minimum, the minimum is rendered less pronounced.

An interesting effect explained by the normal mode analysis is the dependence of propagation loss on the size of the negative gradient of the velocity profile. In general, propagation loss will increase along with the size of the negative gradient, due to the fact that an increase in the negative gradient will tend to decrease the angle θ_b at which energy strikes the bottom thereby decreasing the skip distance. However, this increase in negative gradient also lowers the frequency at which vertexing first occurs, which normally corresponds to the largest skip distance at any frequency. So, in August 1967 and 1968 propagation loss at the lower frequencies is less than the corresponding loss in September 1968 even though much larger negative gradients were observed in velocity profiles taken during the August tests. This circumstance may be attributed to the fact that vertexing took place at about 150 Hz in the former case and at about 350 Hz in the latter. The August skip distances at low frequencies were larger than those in September. Hence, it is compatible with normal mode theory that at low frequencies propagation loss should increase, as the gradient becomes negative, to a maximum and then decrease with an increase in the size of the negative gradient. At higher frequencies in the case of the profiles considered, propagation loss increases with increasingly negative gradient.

The determination of exact skip distance is the major problem in normal mode analysis. As explained previously, the skip distance assumed over the entire range was calculated by using the velocity profile with the largest gradient. As a consequence, whenever there is a large variation in the velocity profile over the range, there is a bias in the calculations of skip distance as a function of frequency.

This can be seen in Table V where the calculated loss per bounce is extremely high at 355 Hz at which frequency the skip distance is a maximum. The bias is especially severe when the bottom loss is high and the velocity profile varies significantly over the range.

An alternate method of determining skip distance would be to take an average of the skip distance over each segment weighted by the length of each segment. One drawback to this method is that segments with large gradients would be weighted evenly with those possessing small gradients whose effect on propagation loss might be smaller than for the large gradient segments. If an analysis similar to the one herein described is performed in the future, Program S1548 should be modified to do the calculations suggested and the results then compared with skip distances calculated for the segment with the largest velocity gradient. Ideally, one would want to know the bottom loss per bounce in each segment and determine the total loss by summing the product of loss per bounce by the number of bounces in each segment. However, experimental determination of bottom loss as a function of frequency for angles of about 75° to 90° relative to the normal would be extremely difficult to perform.

As expected, it was found that, for a given frequency, loss per bounce decreased as the angle of incidence relative to the normal increased. Loss per bounce as a function of frequency did not show any marked trends except for the January data in the case of an irregular bottom. Here, the angle of incidence increased extremely rapidly with frequency and the bottom loss went to zero as the rays nearly vertexed close to the bottom. Since the angle of incidence at the bottom increases with frequency, it might be concluded that in the other cases the bottom loss for a constant incident angle would also increase with frequency.

The theoretical predictions for flat and irregular bottoms differ by small or moderate amounts in four of the tests considered. In January 1968 the difference is considerable, and predictions for the irregular bottom are physically more plausible. This is true also to a lesser degree in the other tests. Therefore, assumption of an irregular bottom seems to be an improvement over that of a flat bottom.

It is hoped that further investigation of the effects described in this memorandum be conducted during daily propagation tests at frequencies of 127, 400, and 170 Hz.

William G. Kanabis
WILLIAM G. KANABIS

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TABLE I
AUGUST 1967

FREQUENCY	SKIP DISTANCE $FT \times 10^2$	Θb	Θs	THEORETICAL LOSS (flat)(db)	THEORETICAL LOSS (Irreg)(db)	MEASURED LOSS db	FLAT BOTTOM: BOTTOM LOSS (db/nMile)	FLAT BOTTOM: LOSS PER BOUNCE (db)	IRREGULAR BOTTOM: BOTTOM LOSS (db/nMile 1)	IRREGULAR BOTTOM: LOSS PER BOUNCE (db)	NUMBER OF BOUNCES
45	7.1	71.4	74.0	55.8	57.0	117.8	3.33	.39	3.32	.39	155
56	8.4	73.6	76.6	56.8	58.2	104.5	2.61	.36	2.53	.35	131
70	10.2	75.8	79.5	58.2	59.8	98.3	2.19	.37	2.10	.36	107
89	12.8	77.7	82.3	59.9	61.6	93.9	1.86	.40	1.76	.38	86
112	17.0	79.2	85.1	61.6	63.3	89.5	1.52	.43	1.43	.41	65
141	34.2	80.4	90.0	63.2	64.9	87.2	1.31	.74	1.22	.69	32
178	18.9	81.4	90.0	64.6	66.3	92.1	1.50	.47	1.41	.44	58
224	17.3	82.2	90.0	65.8	67.6	96.6	1.68	.49	1.58	.46	63
282	21.0	82.9	90.0	66.7	68.8	101.4	1.90	.66	1.78	.62	52
355	18.0	83.4	90.0	67.6	70.1	107.7	2.19	.66	2.05	.62	61
446	11.5	84.0	90.0	68.7	71.6	109.2	2.21	.42	2.05	.39	95
562	10.5	84.6	90.0	70.6	73.5	115.3	2.44	.43	2.28	.40	105

TABLE II
JANUARY 1968

FREQUENCY	SKIP DISTANCE $FT \times 10^2$	Θb	Θs	THEORETICAL LOSS (flat)(db)	THEORETICAL LOSS (Irreg)(db)	MEASURED LOSS db	FLAT BOTTOM: BOTTOM LOSS (db/nMile)	FLAT BOTTOM: LOSS PER BOUNCE (db)	IRREGULAR BOTTOM: BOTTOM LOSS (db/nMile 1)	IRREGULAR BOTTOM: LOSS PER BOUNCE (db)	NUMBER OF BOUNCES
56	7.8	74.4	74.1	56.6	59.2	93.3	2.01	.26	1.86	.24	141
70	9.3	76.7	76.5	58.3	61.2	85.3	1.48	.23	1.32	.20	118
89	11.4	79.2	78.8	60.3	63.6	80.2	1.09	.21	0.91	.17	96
112	13.8	81.2	80.5	62.4	66.2	75.0	0.69	.16	0.48	.11	80
141	16.8	82.8	82.0	64.7	68.9	75.9	0.61	.17	0.38	.11	65
178	20.5	84.3	83.3	67.3	71.9	78.3	0.60	.21	0.35	.12	54
224	25.2	85.5	84.3	70.0	75.1	78.3	0.45	.19	0.17	.07	44
282	31.2	86.5	85.1	73.0	78.6	79.9	0.38	.20	0.07	.04	35
385	39.8	87.5	85.8	76.1	82.5	80.9	0.26	.17	-0.09	-.06	28
446	56.4	88.5	86.2	79.6	87.0	84.8	0.28	.27	-0.12	-.11	19
562	61.6	89.3	86.3	83.6	92.7	90.6	0.38	.39	-0.11	-.12	18

TABLE III
APRIL 1968

FREQUENCY	SKIP DISTANCE FTx102	θ_b	θ_s	THEORETICAL LOSS (flat)(db)	THEORETICAL LOSS (Irreg)(db)	MEASURED LOSS (db)	FLAT BOTTOM: BOTTOM LOSS (db/nMile)	FLAT BOTTOM: LOSS PER BOUNCE (db)	IRREGULAR BOTTOM: BOTTOM LOSS (db/nMile)	IRREGULAR BOTTOM: LOSS PER BOUNCE db	NUMBER OF BOUNCES
56	8.6	74.7	75.8	56.5	59.0	94.2	2.06	.30	1.92	.28	128
70	10.4	77.1	78.4	58.1	60.9	80.6	1.23	.21	1.08	.19	106
89	12.8	79.3	80.9	60.1	63.2	83.0	1.25	.27	1.08	.23	86
112	15.7	81.0	83.1	62.2	65.6	82.4	1.10	.29	0.92	.24	70
141	19.6	82.4	85.1	64.4	68.2	81.5	0.93	.31	0.73	.24	56
178	25.6	83.6	87.3	66.9	70.9	81.0	0.77	.33	0.55	.24	43
224	35.8	84.6	90.0	69.4	73.7	83.0	0.74	.44	0.51	.30	31
282	28.4	85.4	90.0	72.0	76.5	87.3	0.84	.40	0.59	.28	39
355	31.6	86.0	90.0	74.7	79.3	89.0	0.78	.41	0.53	.28	35
446	41.1	86.5	90.0	77.4	81.5	89.7	0.67	.46	0.45	.31	27
562	26.4	87.0	90.0	80.3	81.6	94.2	0.76	.33	0.69	.30	42

TABLE IV
AUGUST 1968

89	13.3	79.1	81.8	59.1	62.3	94.8	1.95	.43	1.78	.39	83
112	16.7	80.7	84.1	60.8	64.4	90.0	1.60	.44	1.60	.39	66
141	22.3	82.1	86.7	62.6	66.6	89.6	1.48	.55	1.26	.47	49
178	29.2	83.2	90.0	64.3	68.8	93.7	1.61	.78	1.36	.66	38
224	24.9	84.1	90.0	65.9	70.9	99.0	1.81	.75	1.54	.64	44
282	25.0	84.9	90.0	67.4	72.8	104.8	2.04	.85	1.75	.73	44
355	21.9	85.5	90.0	68.6	74.5	108.2	2.16	.79	1.84	.67	50
446	21.4	86.0	90.0	69.8	76.0	110.5	2.22	.79	1.89	.67	51
562	21.9	86.5	90.0	71.0	77.2	112.4	2.26	.82	1.92	.70	50

TABLE V
SEPTEMBER 1968

FREQUENCY	SKIP DISTANCE FTx10^2	θb	θs	THEORETICAL LOSS (flat)(db)	THEORETICAL LOSS (Irreg)(db)	MEASURED LOSS (db)	FLAT BOTTOM: BOTTOM LOSS (db/nMile)	FLAT BOTTOM: LOSS PER BOUNCE (db)	IRREGULAR BOTTOM: BOTTOM LOSS (db/nMile)	IRREGULAR BOTTOM: LOSS PER BOUNCE (db)	NUMBER OF BOUNCES
70	9.8	76.1	77.9	57.4	60.3	105.5	2.63	.43	2.47	.40	112
89	11.9	78.0	80.2	59.1	62.4	101.2	2.30	.46	2.12	.42	92
112	14.4	79.6	82.2	60.8	64.6	97.2	1.99	.48	1.78	.43	76
141	17.7	80.8	83.9	62.6	67.0	94.4	1.74	.51	1.50	.44	62
178	22.3	81.8	85.6	64.4	69.4	98.8	1.88	.70	1.61	.60	49
224	29.5	82.6	87.3	66.0	71.8	105.9	2.18	1.07	1.86	.92	37
282	36.3	83.1	90.0	67.4	74.1	106.6	2.14	1.30	1.78	1.07	30
355	48.6	83.6	90.0	68.3	76.1	108.9	2.22	1.80	1.79	1.45	23
446	32.7	83.9	90.0	68.8	77.8	103.5	1.90	1.03	1.40	.77	34
562	17.7	84.3	90.0	69.3	79.0	108.6	2.15	.63	1.62	.48	62
707	16.2	84.6	90.0	70.7	79.8	112.7	2.30	.62	1.80	.49	68

FIGURE I

U. S. Navy Underwater Sound Laboratory
NP24 - 33460 - 6 - 68

Official Photograph

Effect of Variable Depth on Rays

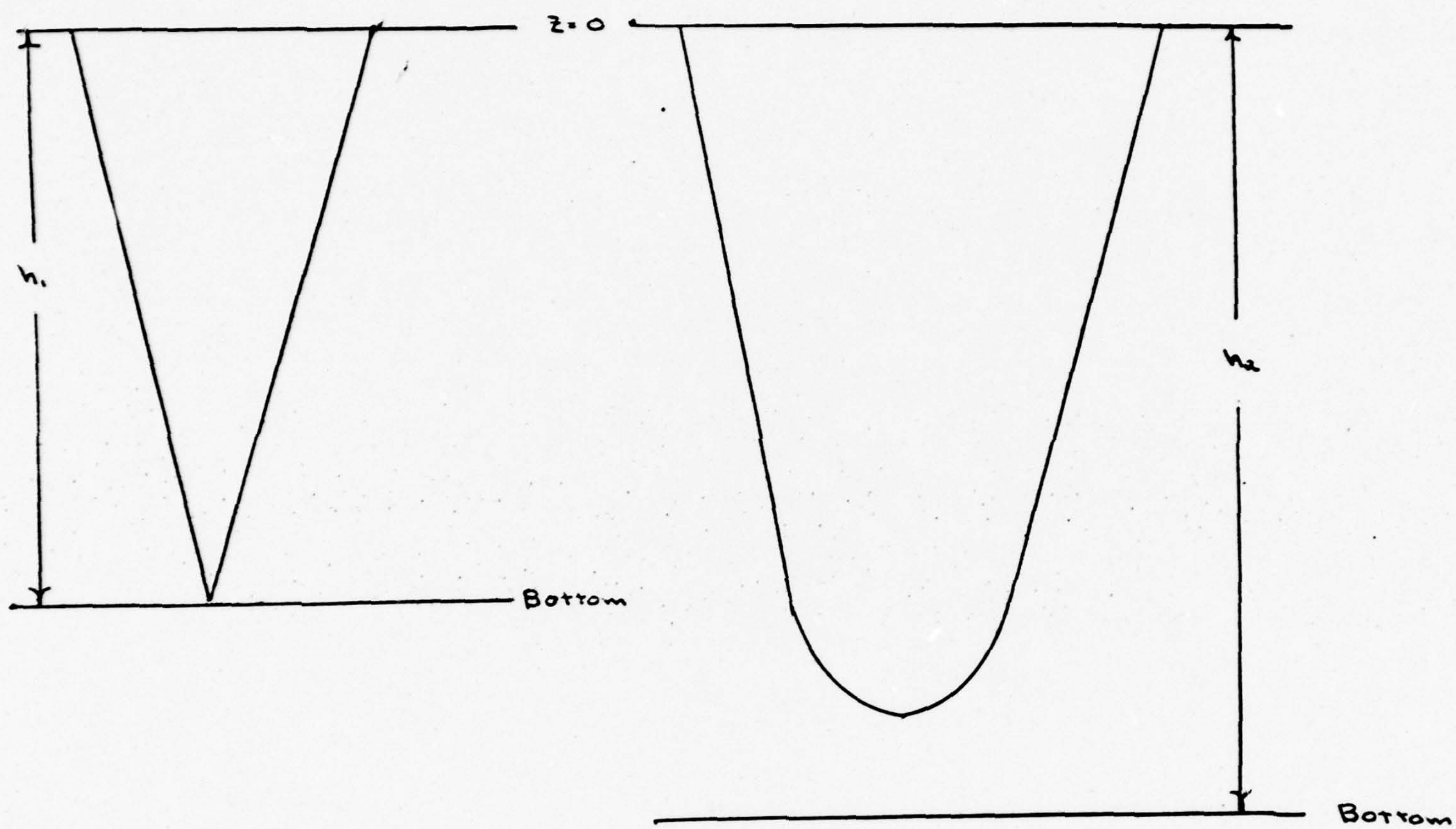

FIGURE II

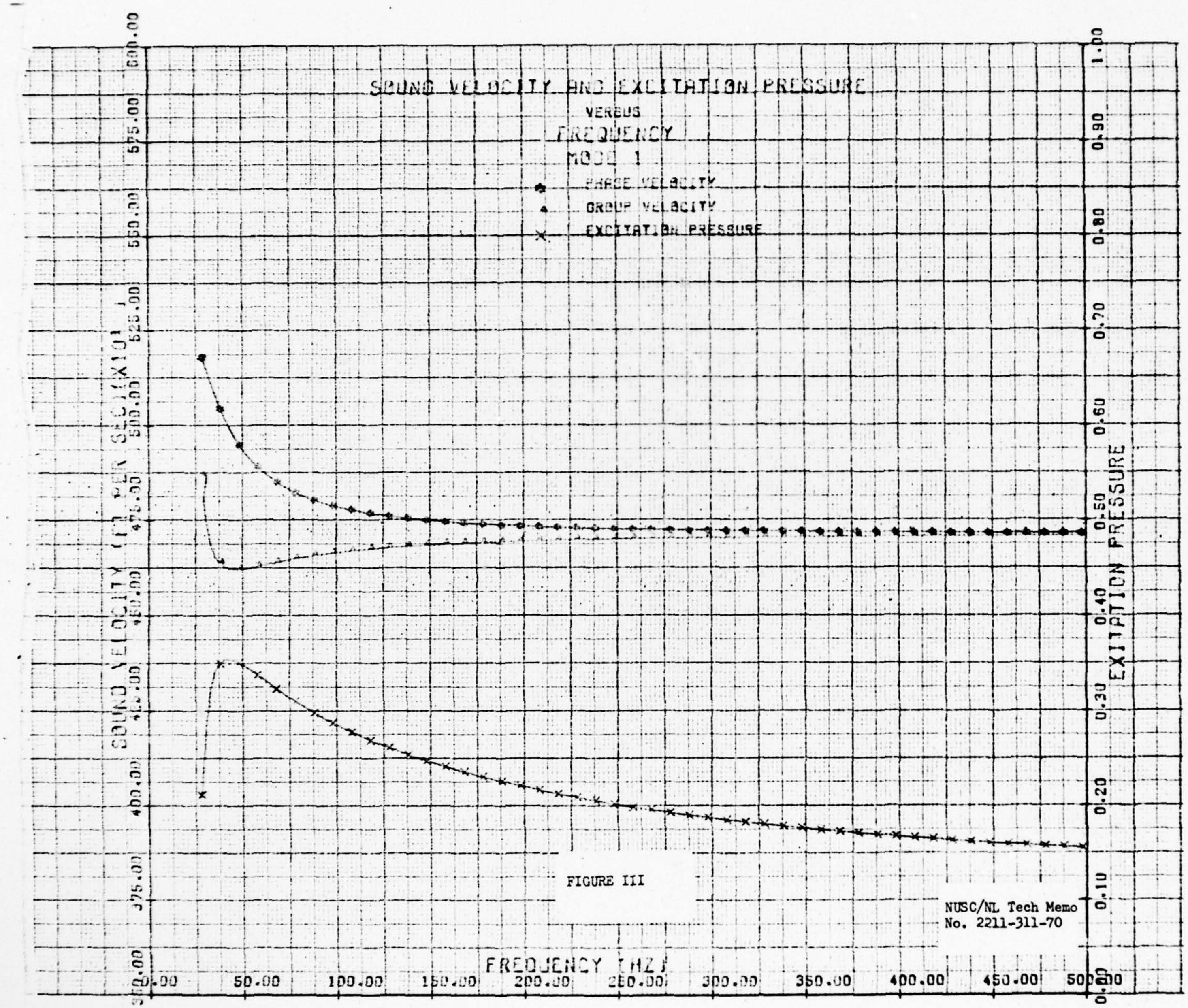

FIGURE III

NUSC/NL Tech Memo
No. 2211-311-70

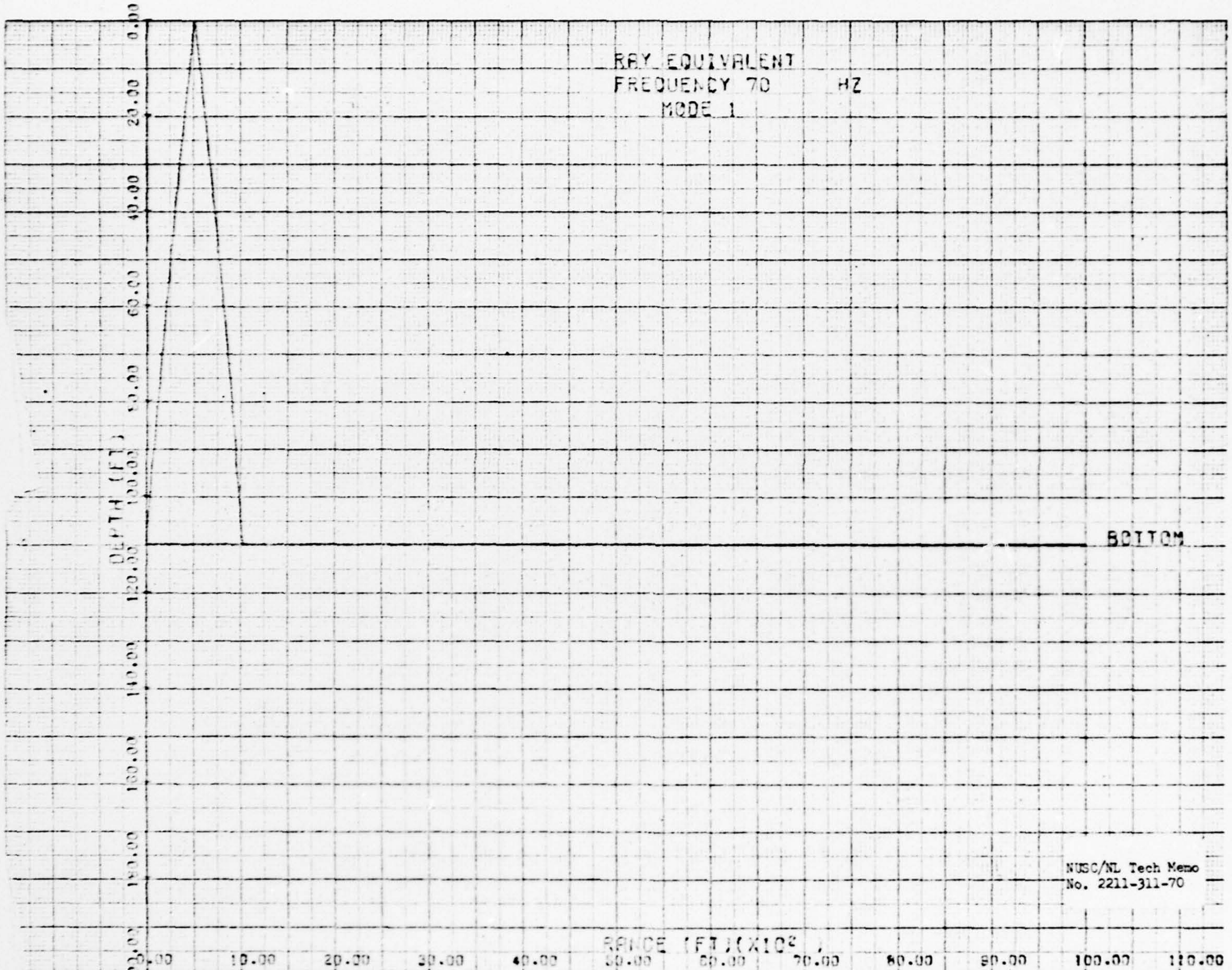

FIGURE IV

CALIFORNIA CHART NO. 02

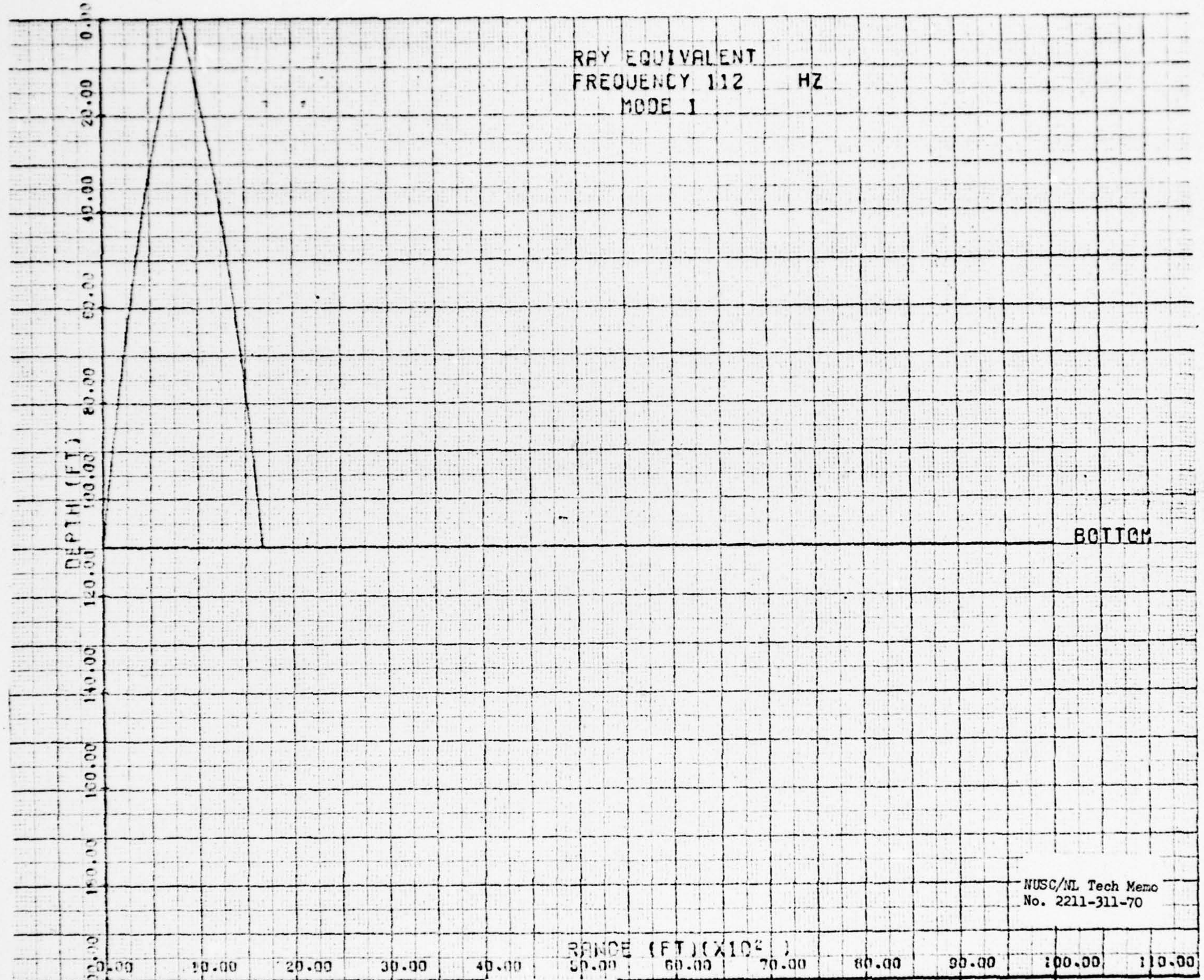
RAY EQUIVALENT
FREQUENCY 112 HZ
MODE 1
BOTTOM
DEPTH (FT)
RANGE (FT)(X10²)
NUSC/NL Tech Memo
No. 2211-311-70

FIGURE V

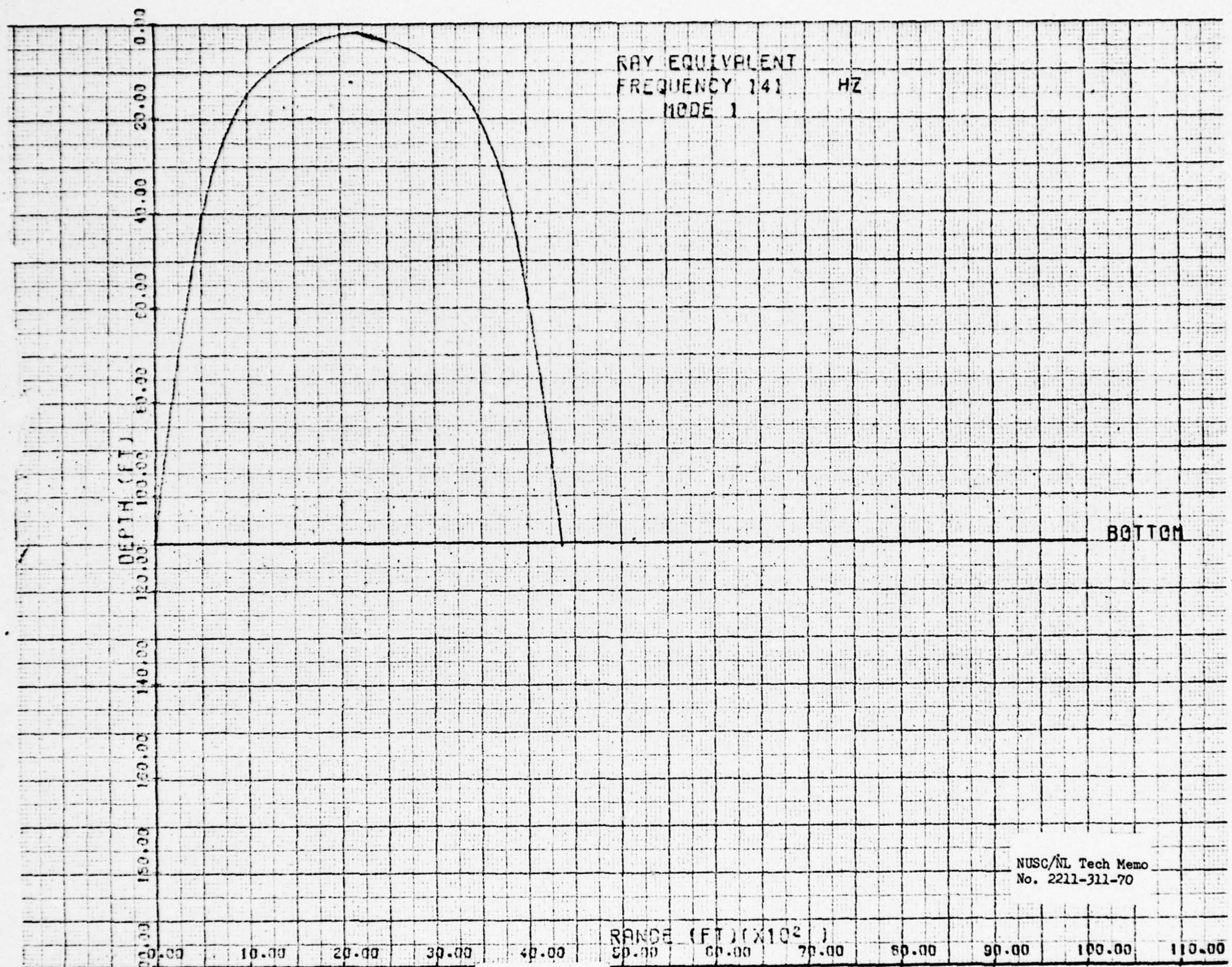
RAY EQUIVALENT
FREQUENCY 141 HZ
MODE 1
BOTTOM
DEPTH (FT)
0.00
20.00
40.00
60.00
80.00
100.00
120.00
140.00
160.00
180.00
200.00
RANGE (FT)(X10²)
0.00
10.00
20.00
30.00
40.00
50.00
60.00
70.00
80.00
90.00
100.00
110.00
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FIGURE VI

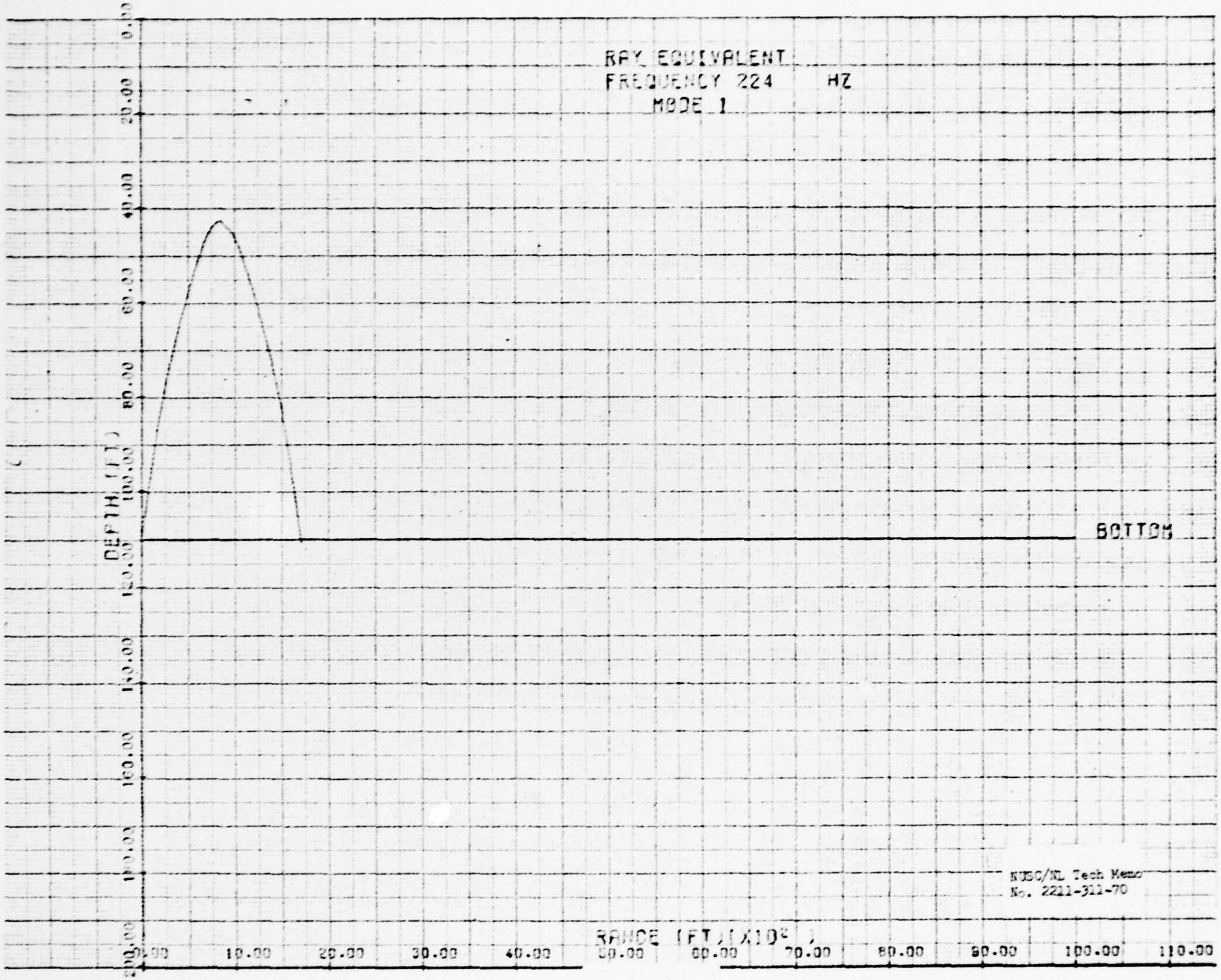
RAY EQUIVALENT
FREQUENCY 224 HZ
MODE 1
BOTTOM
DEPTH (FT)
0.00
20.00
40.00
60.00
80.00
100.00
120.00
140.00
160.00
180.00
200.00
RANGE (FT)(X10²)
0.00
10.00
20.00
30.00
40.00
50.00
60.00
70.00
80.00
90.00
100.00
110.00
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FIGURE VII

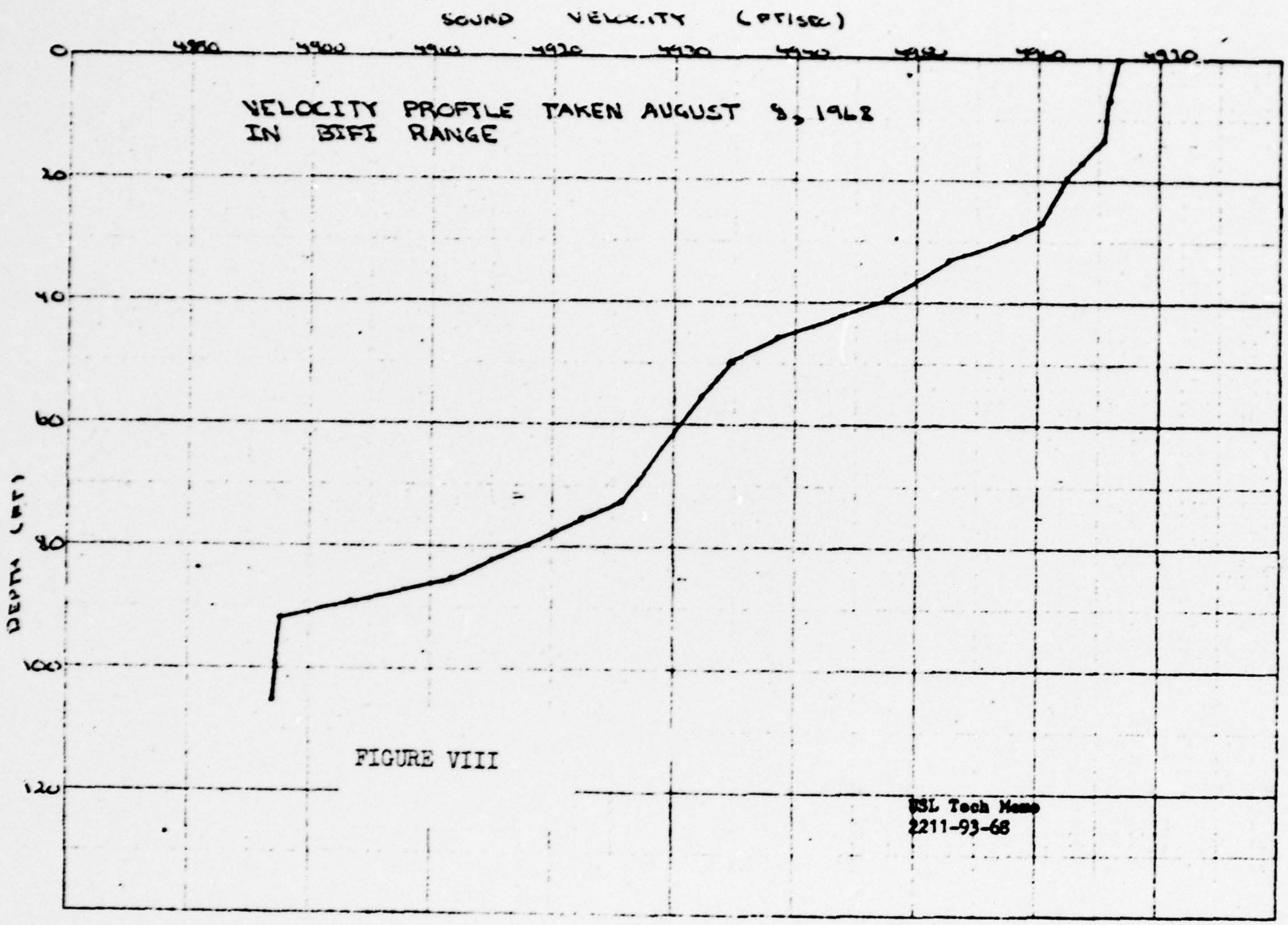

FIGURE VIII

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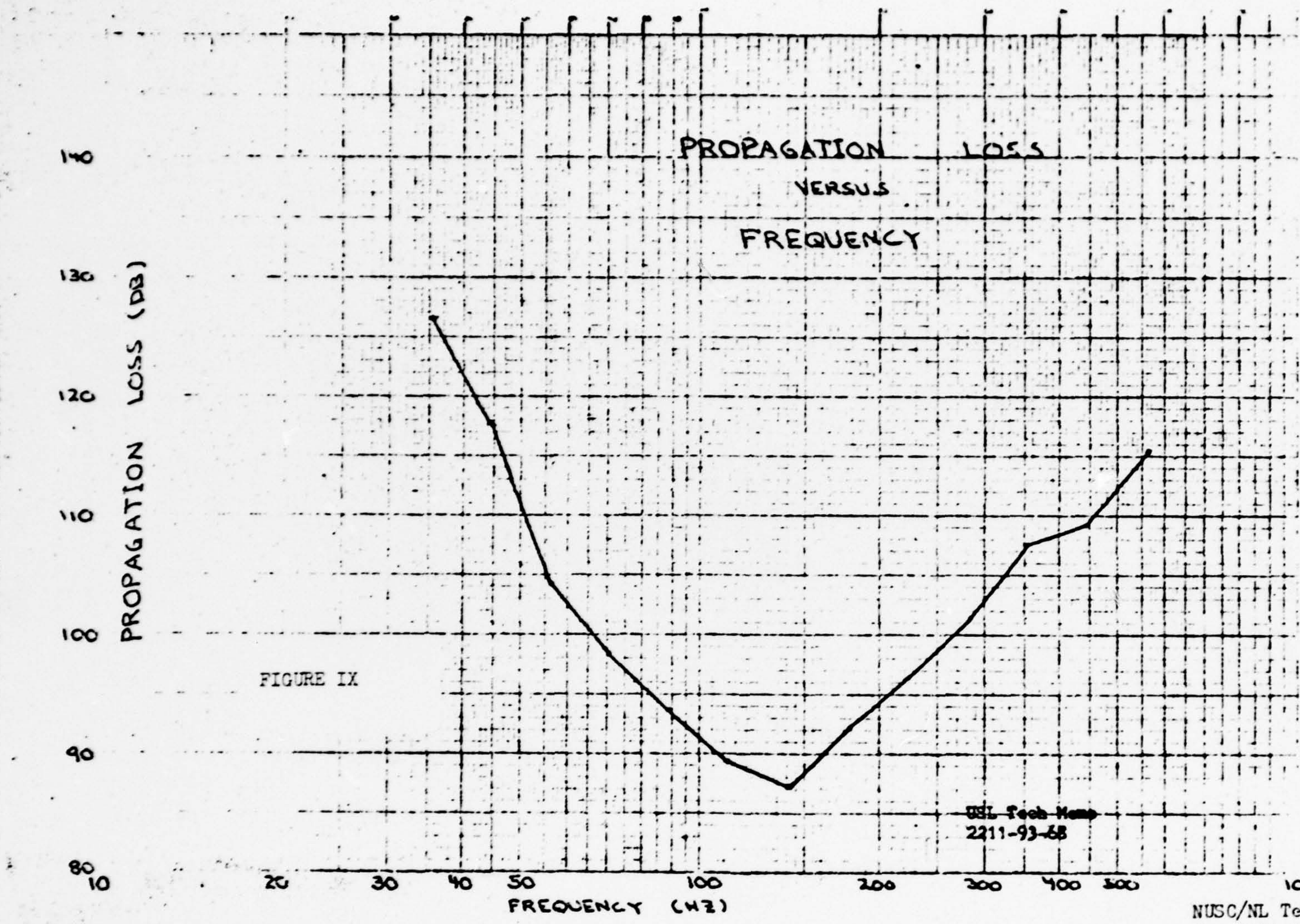
U. S. Navy Underwater Sound Laboratory
NP24 - 33461 - 6 - 68

Official Photograph


PROPAGATION LOSS
VERSUS
FREQUENCY
FIGURE IX
PROPAGATION LOSS (DB)
140
130
120
110
100
90
80
10
20
30
40
50
100
200
300
400
500
1000
FREQUENCY (HZ)
USL Tech Memo
2211-93-68

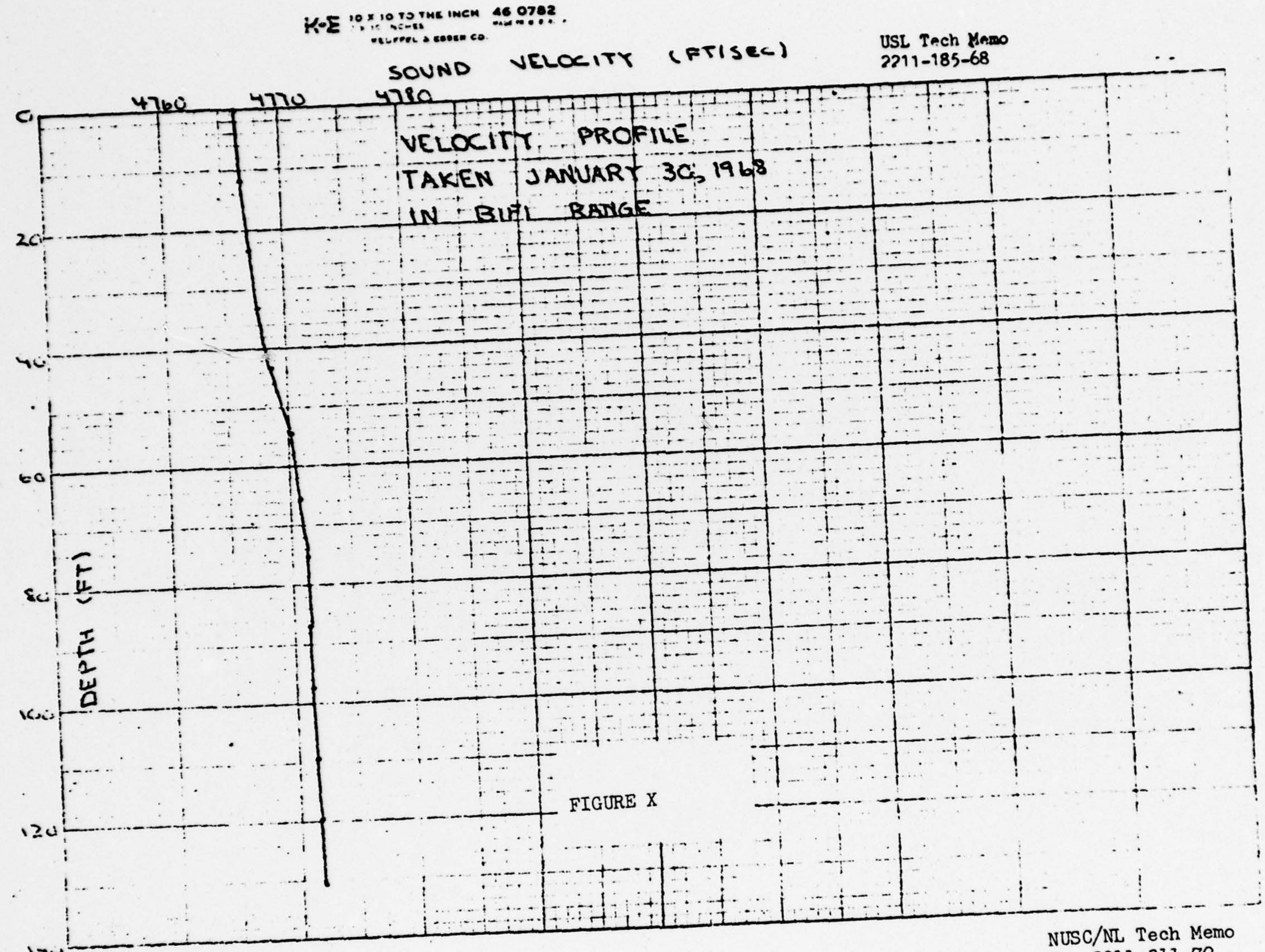

K-E 10 X 10 TO THE INCH 46 0782
KEUFFEL & ESSER CO.
SOUND VELOCITY (FT/SEC)
4760
4770
4780
VELOCITY PROFILE
TAKEN JANUARY 30, 1968
IN BIFI RANGE
DEPTH (FT)
0
20
40
60
80
100
120
140

FIGURE X

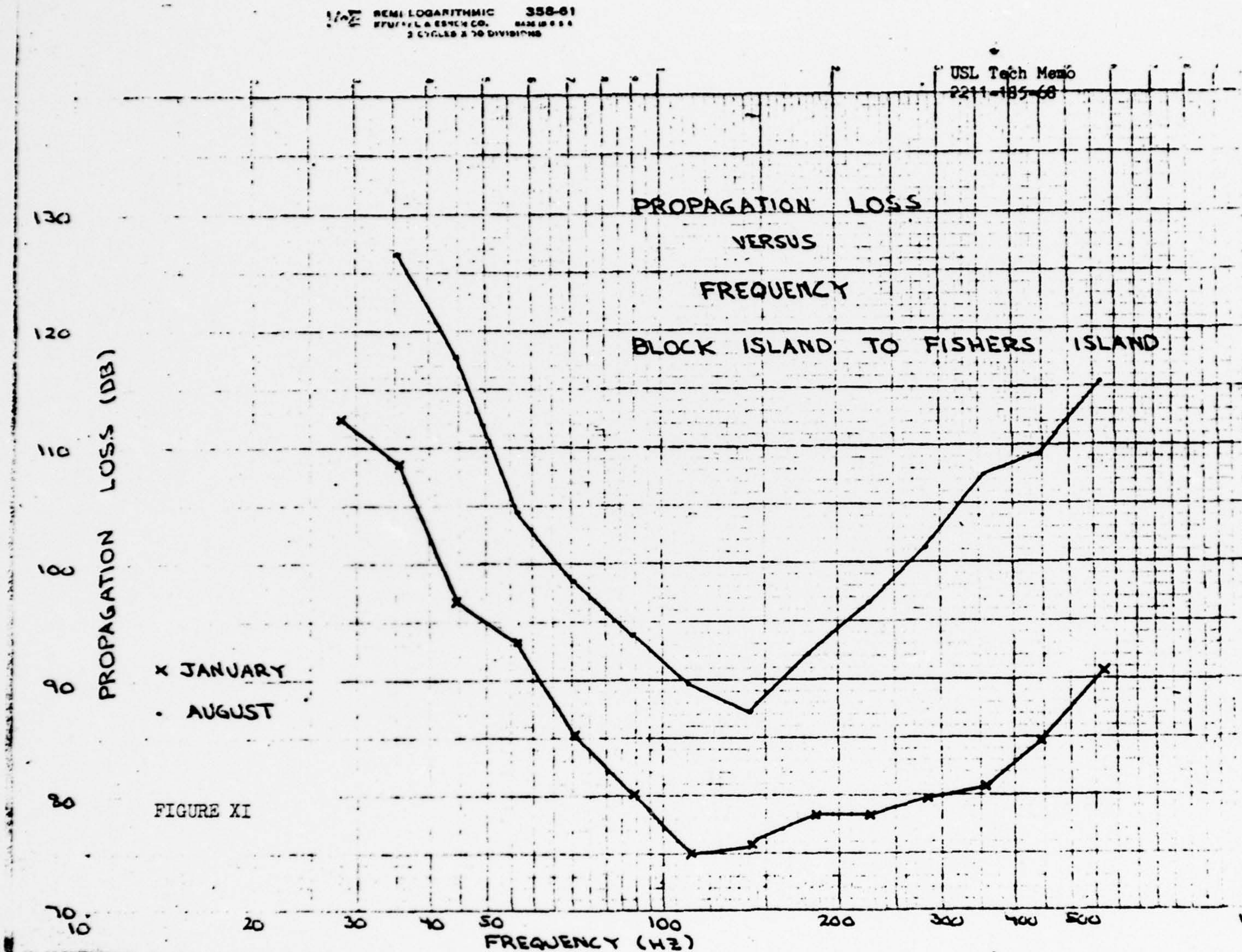

SEMI-LOGARITHMIC 358-61
USL Tech Memo
2211-185-68
PROPAGATION LOSS
VERSUS
FREQUENCY
BLOCK ISLAND TO FISHERS ISLAND
× JANUARY
· AUGUST
PROPAGATION LOSS (DB)
130
120
110
100
90
80
70
10
20
30
40
50
100
200
300
400
500
1000
FREQUENCY (HZ)

FIGURE XI

VELOCITY PROFILES TAKEN APRIL 19, 1968 IN BIPI RANGE

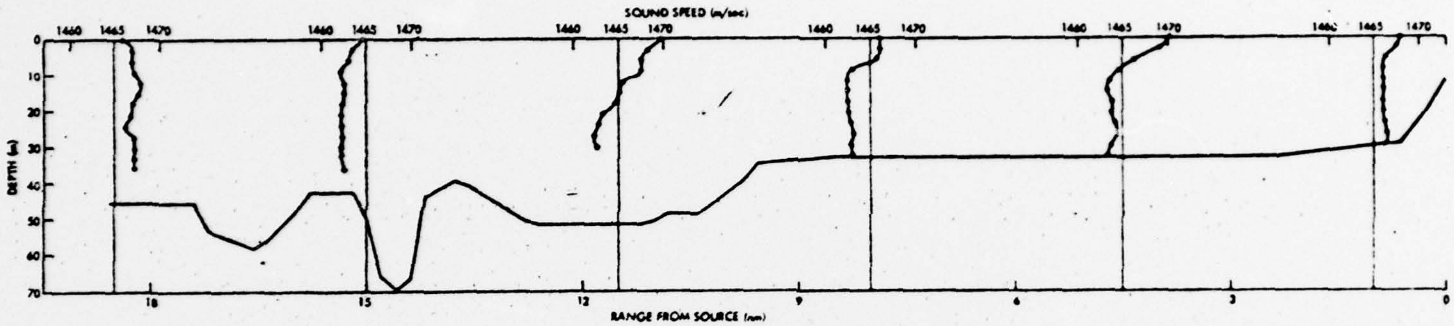


FIGURE XII

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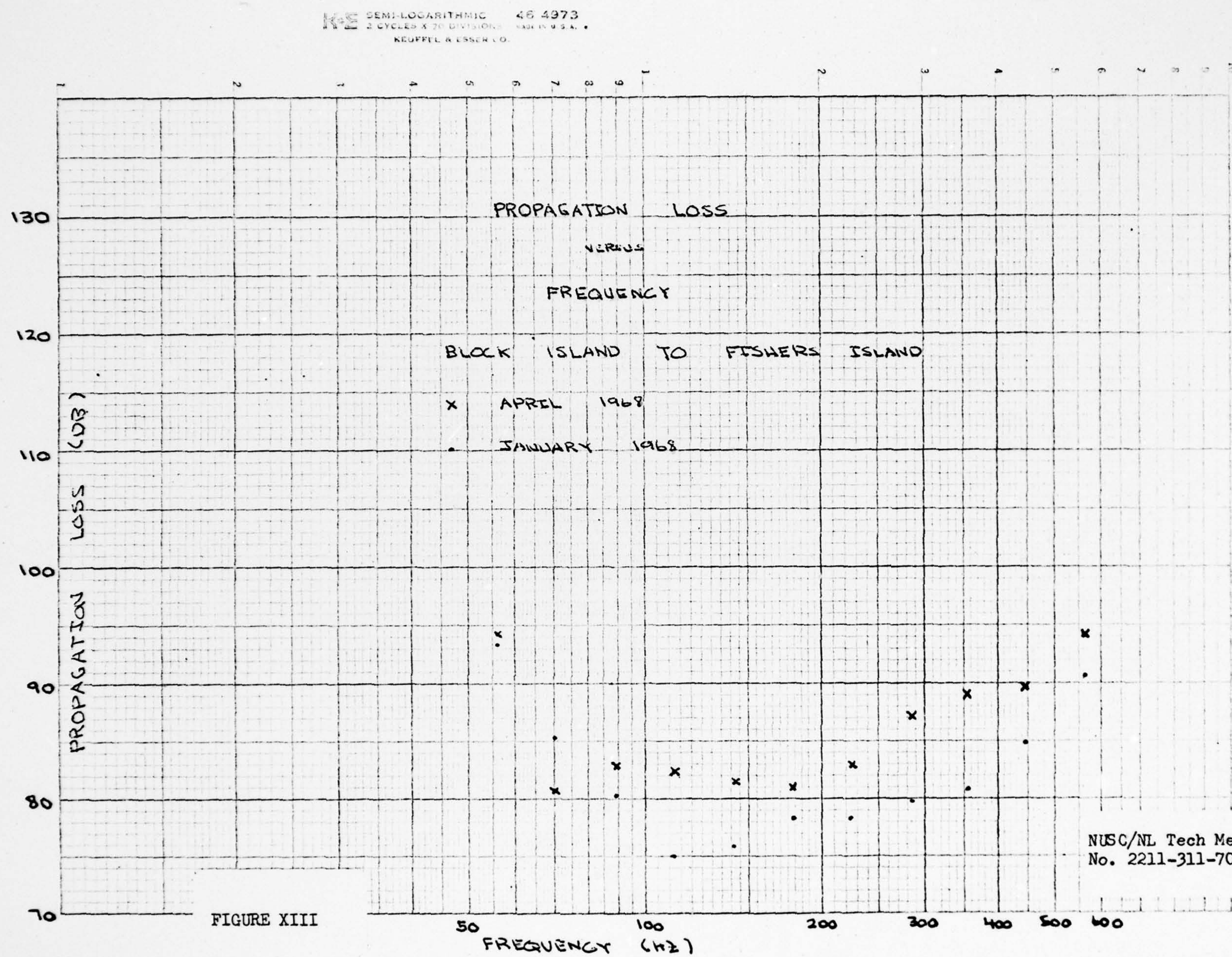
K+E SEMI-LOGARITHMIC 46 4973
2 CYCLES X 70 DIVISIONS MADE IN U.S.A.
KEUFFEL & ESSER CO.
PROPAGATION LOSS
versus
FREQUENCY
BLOCK ISLAND TO FISHERS ISLAND
x APRIL 1968
• JANUARY 1968
PROPAGATION LOSS (DB)
130
120
110
100
90
80
70
50
100
200
300
400
500
600
FREQUENCY (HZ)

FIGURE XIII

VELOCITY PROFILES TAKEN AUGUST 28, 1968 IN BIFI RANGE

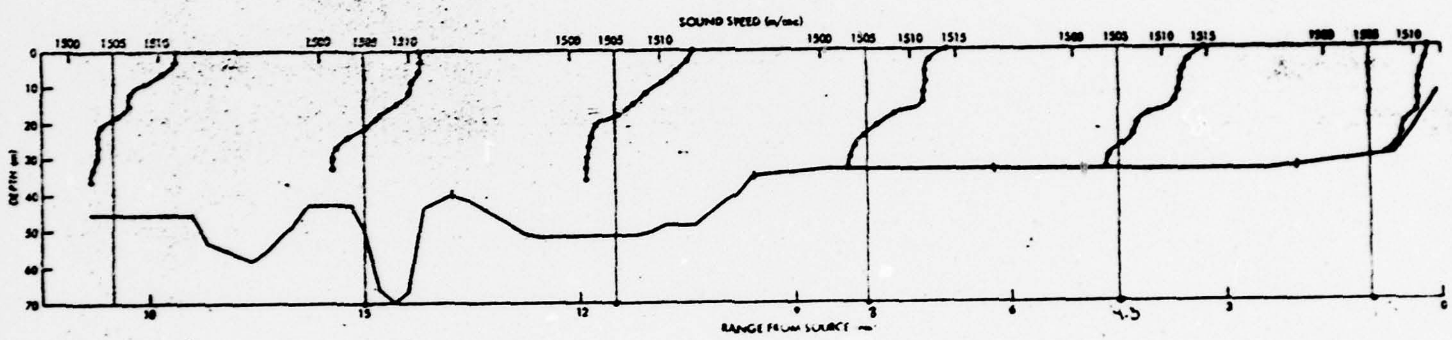

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FIGURE XIV

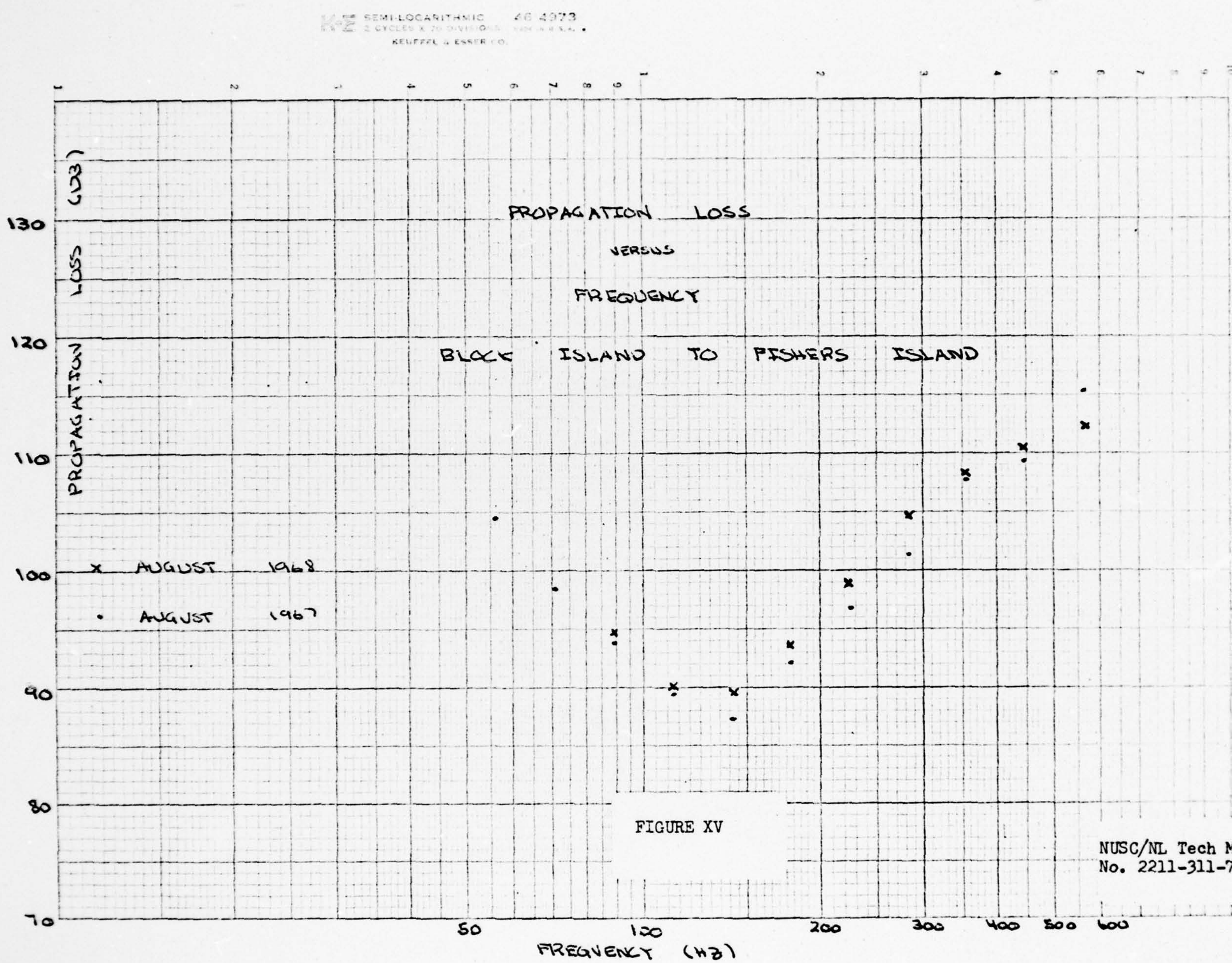

FIGURE XV

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VELOCITY PROFILES TAKEN OCTOBER 2, 1968 IN BIFI RANGE

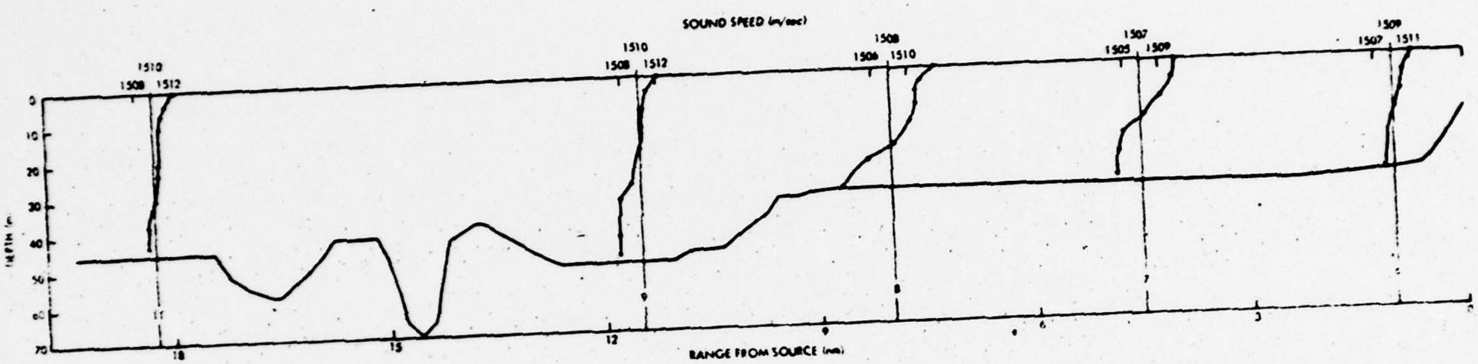

FIGURE XVI

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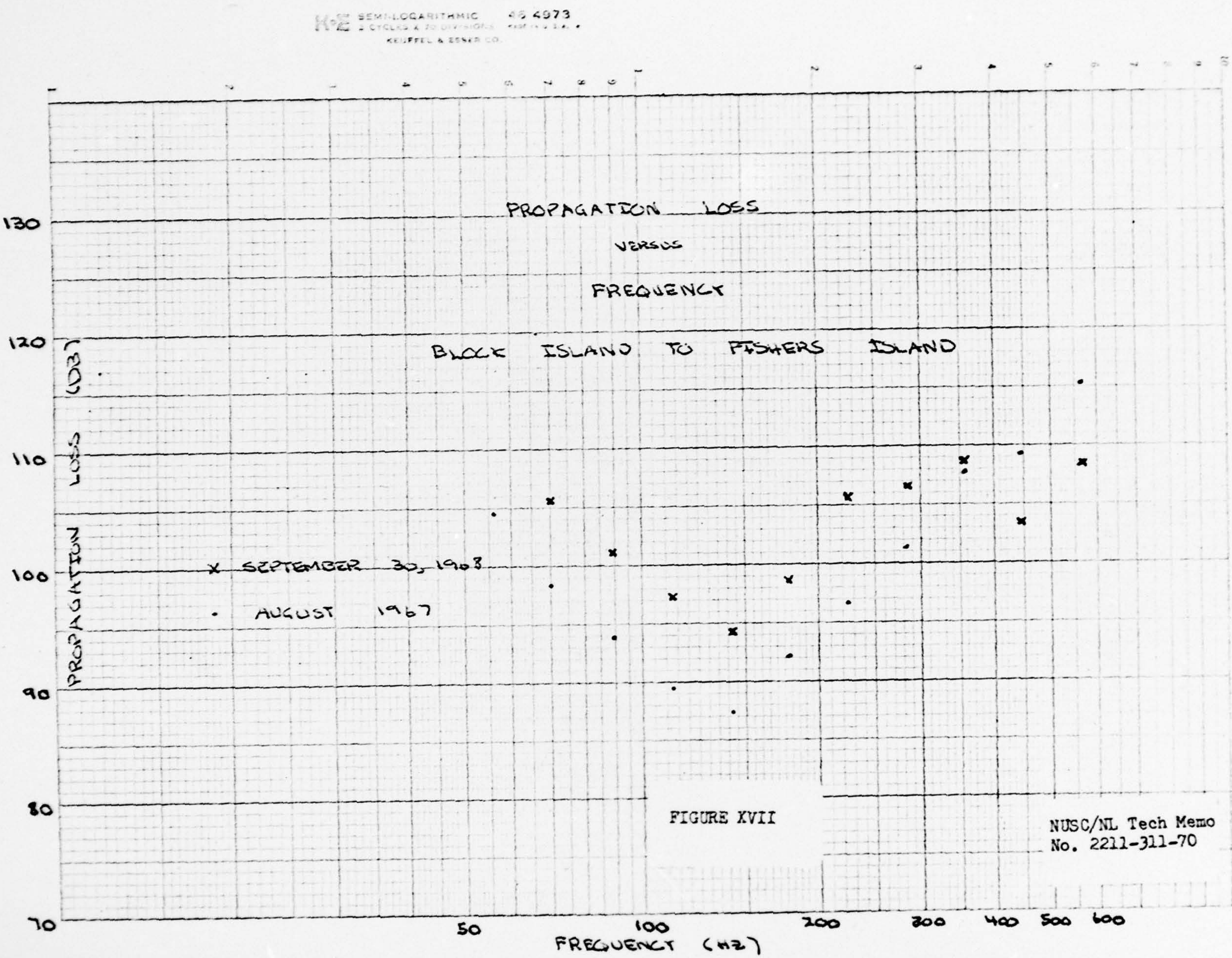

FIGURE XVII

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